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INFLUENCE OF STRESS CORROSION ON STRENGTH OF GLASS FIBERS

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Second Bi-Monthly Progress Report

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I. SUMMARY

A program of static fatigue tests on single filaments of E-glass is underway. Presently, tests at room temperature and normal humidity are nearly completed and these data are being analyzed. Static fatigue, or delayed failure, occurs under such conditions at stress levels as low as 200,000 psi; and a fatigue limit, if one exists, has not yet been determined. Tests at liquid nitrogen temperature and in an active desiccant at room temperature will follow the present series.

II. INTRODUCTION

In the initial phase of this program, we are obtaining data on the distribution of failure times for supposedly identical fiber segments when they are placed under sustained constant tensile stress. This distribution can be the result of several factors which include the differences in flaw severity in each of the short (1-inch) segments of fiber at the start of the test, as well as any processes by which the severity of flaws becomes altered during the course of the test. The former category of differences can be expected to determine whether or not a given fiber will withstand the relatively rapid application of the dead weight load initially. On the other hand, any failure which occurs after some period of time under load requires that some changes have affected the structure which has been resisting the applied load.

It is expected that the results of static fatigue tests, under a range of loads and in the particular environments selected for this program, will help us understand what the processes are which cause the practical strength of glass fibers to be so much less than the theoretical or instantaneous strength. For

example, if a substantial range in the severity of flaws exists in similar fibers before test, then we should expect that the proportion of those fibers which will not withstand the initial application of load will increase as the load is made larger. For those which do survive the loading, the distributions of their failure times which we observe as a function of the static load should depend upon whether or not the degradation processes are influenced by the stress level. If the process <u>is</u> stress dependent, then it would seem likely that the distribution of failure times would be narrower as the stress level is raised. Conversely, if the slow degradation is independent of stress level, then the patterns of failure times for those fibers which survive initial loading should also be unaffected by load level, but may remain a function of temperature, humidity or some other variables.

Another source of information about the failure mechanisms in fibers might be a comparison of the time intervals required for slow degradation to cause failure in one after another of the fibers in a group at equal applied load. Assuming a linear distribution of initial flaw sizes, uniform time intervals between failures would

indicate that flaw growth rate is not sensitive to initial size or severity. Intervals which increase as each fiber fails in sequence could mean that the smaller flaws (i.e., the more durable fibers) degrade at slower rates than the larger ones.

When static fatigue tests are conducted at liquid nitrogen temperatures or in desiccants, comparisons with normal environment failure patterns should allow us to deduce the kinds of processes responsible for delayed failure and reduced strength.

III. EXPERIMENTAL RESULTS

Fiber Production and Storage

Sufficient E-glass monofilament has been drawn to supply all of the tests which have been scheduled for this program. These fibers were gathered from our single orifice melting crucible at a drawing speed of approximately 800 feet/minute and with the glass batch temperature at 2425°F. Orifice temperature was considerably lower but not measured directly. The resulting fiber diameters were in the range of 0.00048-0.00050 inch. All of the fibers were collected within a three-hour period, wound on forks and stored over silica gel in a protective enclosure.

Test Equipment and Procedure

For static fatigue testing of fibers in a variety of environments, including actual submergence in desiccant solutions, a machine was designed which applies dead weight loads to each of twelve fibers and automatically records the start of each individual test and the failure times. This machine is shown in Figure 1. Fibers with one inch gage lengths are positioned vertically on the rack near the bottom of the apparatus between two rows of aluminum potting blocks into which the fiber ends

are fastened with sealing wax. Each row of blocks is supported initially from below by a ledge on the rack. Loading weights are hung from the lower blocks, and the upper blocks are connected through a system of levers to a mechanism which raises the whole assembly free from its support when a test is to be started. The lower portion of the apparatus, containing the fibers, can be enclosed in a tank for tests at liquid nitrogen temperature, etc.

In actual operation, when the fibers have been positioned on the rack, the weight of each lower block is measured by lifting it slightly from its supporting shelf by a torsion balance adapted for this purpose. The fixtures employed in this step are shown in Fig. 2. The weight which must be added to each fiber holder can then be accurately computed so that all fibers in a given test are under the same total dead load.

Upon connection to the upper lifting mechanism, each fiber is put under a slight pre-tension. This is provided by the small lead weights which can be seen hanging from the rear end of the lever arms in Fig. 1, and has been adjusted not to exceed 1-1/2 grams. The purpose of the pre-tension is twofold: (1) to remove

slack from the suspension train and (2) to insure open electrical circuits to the timers whenever the main loads are not actually borne by the fibers. The pre-tension load amounts to less than 10% of the smallest fatigue load used in these tests.

To begin a fatigue test, the large knob, visible on the side of the machine in Figure 1, is rotated about one-half turn. This knob is directly connected to a cam which, in turning, allows levers to descend under the action of compression springs. These levers contact those to which the fibers are attached, simultaneously raising the fiber assemblies to apply the dead loads and completing individual electrical circuits to start the timers. When a fiber breaks, the lower block drops with the dead load, while the pre-tensioning load immediately opens that timer circuit.

Fatigue Results-Room Temperature and Normal Humidity

Information on the behavior of E-glass fibers under static tensile load would be most useful if a simple correlation could be found relating the tensile stress to the failure time. It would be particularly valuable if some function of load and time could be ascertained which would predict the integrated life expectancy of a fiber under varying stresses.

In gathering any kind of strength data on glass fibers, one is always faced with the problem of how to handle the variations in presumably identical samples. Static fatigue tests in normal atmosphere are no exception. The value of attempting a direct plot of failure time versus load is doubtful simply because almost any load which produces fatigue failures as well as instantaneous failures will run over several logarithmic decades of time. It is revealing, however, to compare the time distribution of failures at the various stress levels, and this is done in Figure 3, for the tests completed thus far in normal atmosphere. In this figure, the height of the bars on each graph indicates the percentage of fibers in that test which failed within each particular logarithmic time decade. Within the first decade, a distinction has been made between these which broke immediately upon loading and those which required a distinguishable time interval (more than 2 seconds) to fail.

Although we feel it is still too early in this program to draw important conclusions, several things are readily apparent from Figure 3. First, static fatigue, extending over several logarithmic decades

of time in seconds, is obviously present at all stress levels from 400,000 psi down to 200,000 psi. Second, the percentage of immediate failures decreases quite uniformly as the stress level is reduced, as would be expected if a continuous range of flaw sizes or severities exists. This effect is plotted in Figure 4. Third, for those fibers which survive the initial application of load, the most probable failure time becomes longer as stress level is reduced. Nevertheless, with the wide distribution of failure times obtained at all stress levels, one cannot say that a fatigue limit is indicated, at least down to 200,000 psi.

Fatigue Tests-Liquid Nitrogen Temperature

Although the data obtained in normal atmosphere raise many questions which are difficult to answer without many additional tests, we are proceeding with the low temperature fatigue tests as originally planned. The cold chamber has been constructed, and controls for maintaining a liquid nitrogen level automatically for an extended period of time are being assembled. The samples will be in the nitrogen gas phase and at -196 °C before the main loads are applied.

From our prior experience with short-term testing of fibers in an Instron tensile machine, we should expect that the load range which will cause some immediate failures will be higher at -196 °C than at room temperature. However, since we have not used loading rates in the Instron anywhere near as high as that which occurs in the fatigue test, some preliminary experimentation will likely be required to choose appropriate loads.

IV. FUTURE PLANS

Static fatigue testing at liquid nitrogen temperature will begin in August and will probably continue through September. During this period, also, we shall design and build the facilities needed to run long-term tests in active desiccants. While this is, perhaps, a most interesting phase of fiber research, it also poses some very difficult technical problems. The aim, of course, is to eliminate the effects of external moisture without introducing any other important variables into the system. Our first desiccant medium will be an ether solution of aluminum hydride.

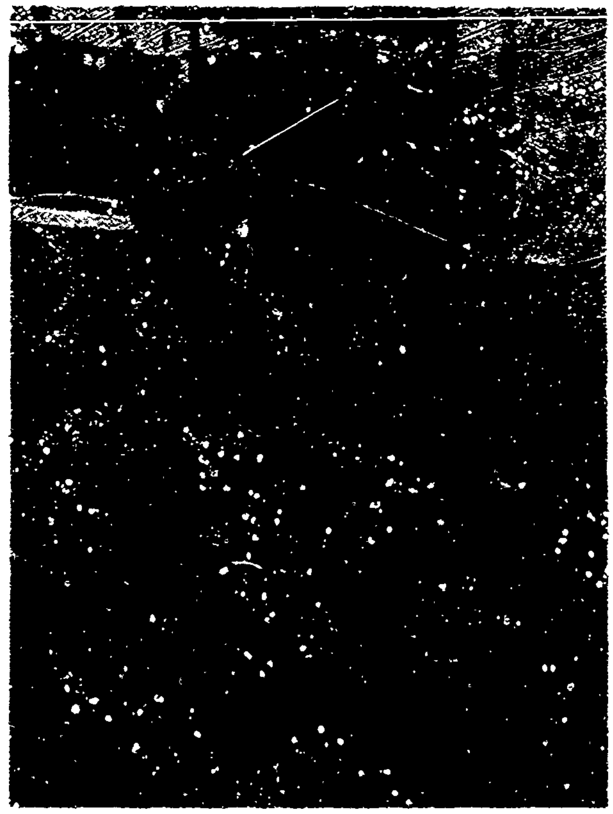

Figure 1

Static Fatigue Test Apparatus

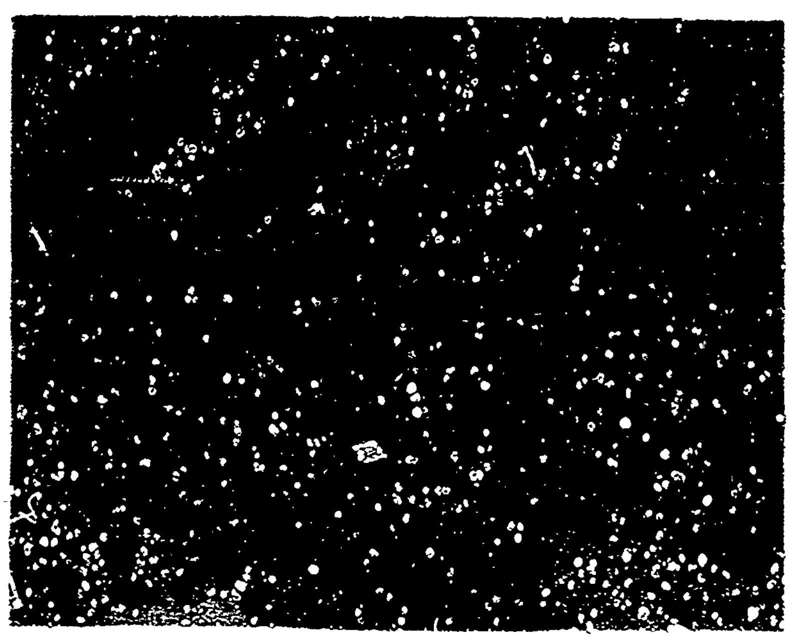

Figure 2

Weighing Device

Figure 3

Static Fatigue of E - Glass Fibers
Distribution of Failure Times

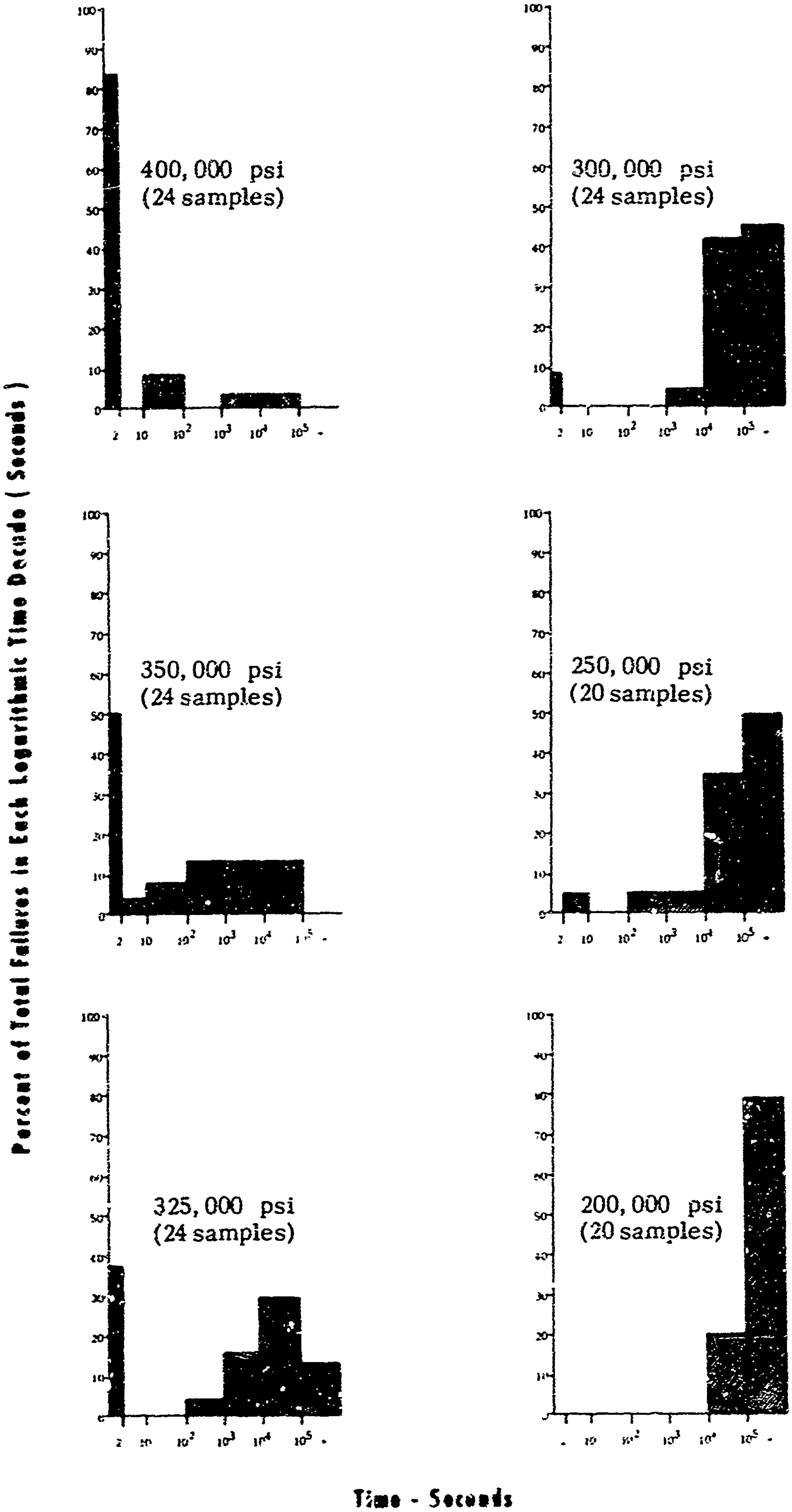

Figure 4

Failure Under Rapid Application of Dead Load
E-Glass Single Fibers
Normal Room Atmosphere